Multifield Fragmentation

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A solid object subjected to external forces will deform. If the forces are large the deformation can be rapid and the object can break up into fragments. Hand grenades and pipe bombs are simple examples in which the forces are created by a high explosive whose pressures cause fragmentation of the confining case. Prediction of the fragmenting process, and in particular its prevention, is ubiquitous. The subject is central to applications including the safety of buildings, bridges, vehicles, and manufacturing equipment, as well as in weaponry.

An understanding of the physics of fragmentation is facilitated by a so-called multifield formulation, which permits the study of the force-generating media concurrently with the force-affected media, so that their interactions are fully coupled. Each medium is represented by a set of averaged variables, called field variables, representing the thermodynamic state of the medium at all points. When the field variables are associated with an element of mass, the description is said to be in the Lagrangian frame of reference; when the field variables are associated with a fixed location in space, the description is in the Eulerian frame.

We have developed a scheme that permits the choice of frame according to the medium. For a solid material, initially intact, and for which eventual fragmentation is of interest, the Lagrangian frame is appropriate because it affords the highest possible accuracy of the material stress. For a fluid material (like a high pressure gas or liquid) the Eulerian frame is most accurate because it permits arbitrary deformation.

The strip of images in Fig. 1 illustrates use of this mixed-frame approach to the simulation of a fragmenting slab of metal. Here in the simulation time increases from left to right. An initially rectangular metal slab occupies the left side of the space, and a nonviscous fluid is in the right side. At time zero, a uniform acceleration is applied to the domain (as if it were a very fast elevator) causing the slab to press against the bottom boundary, and pull at the top boundary. Colors show values of a damage progress variable: blue is completely undamaged; light-blue and green indicate intermediate damage; red is fully damaged (failed) material.

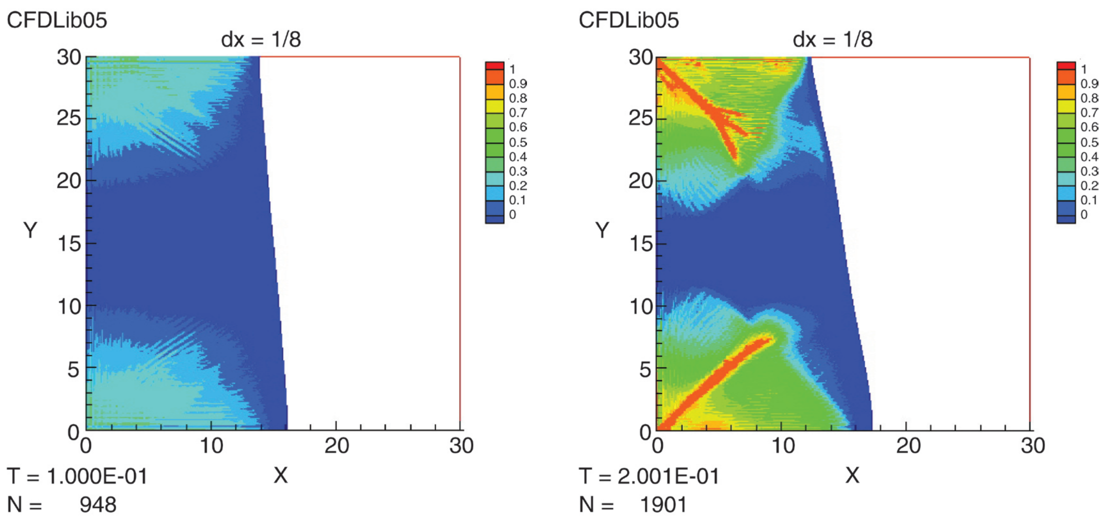

Fig. 1. A mixed-frame approach to the simulation of a fragmenting slab of metal. The simulation time increases from left to right.

Initial damage occurs in the upper and lower left corners where the forces are the greatest, and where a crack first appears in each corner. As the damage progresses, the cracks are seen to branch out and intersect, leaving a pile of rubble consisting of a variety of large and small fragments. Calculations of this type are used to verify theoretical expressions for the material stress history of the solid medium. Once verified, these theories are used for a wide variety of technological applications in defense, industry, and in academia.

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